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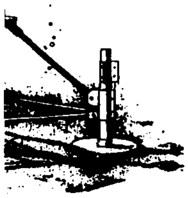

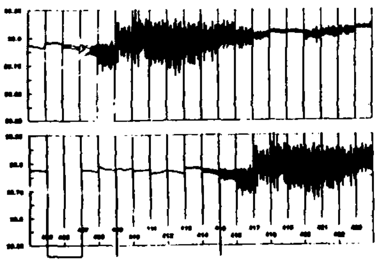

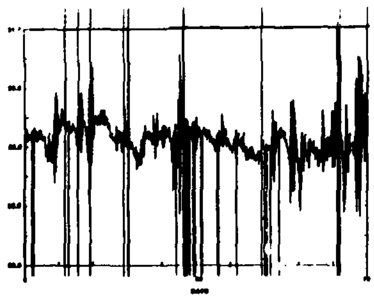

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(2)

QUALITY CONTROL AND MANAGEMENT OF OCEANOGRAPHIC WAVE-GAGE DATA

by

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The processing, analysis, and quality control of oceanographic wave data is a complex procedure. Quality control at each step of the analysis is vital to ensure that the results accurately represent the physical environment that was monitored. A central theme of this report is that a skilled analyst must examine the data graphically.

Three of the most common sources of data errors are: (1) malfunctions of the instrument during deployment; (2) errors during data transfer to the user's computer; and (3) inadequate validation of the software used to process the data. Of the three classes of error, gage malfunction is the most serious, because often the data are irretrievable. Data-transfer problems are subtle and can usually be corrected. The software that is used to process the data must be developed and used with a sensitivity to the severe conditions that are often encountered in the marine environment.

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Preface

This report describes various aspects of the identification and the repair of data errors that can occur when oceanographic wave data are collected and analyzed. The document is intended to assist the following users of oceanographic data:

a. Investigators who plan to deploy instruments at sea and must learn more about how the gages work and how to maximize the possibilities of recovering usable data.

b. Infrequent users of the instruments who may have encountered unexpected and unfamiliar problems.

c. Analysts who work with the data and may be able to use some of the examples in their particular situations.

d. Users of oceanographic data who have not been involved in the collection and analysis of raw data and who may not be aware of how difficult the quality-control procedures can be.

The information presented in this report was obtained from research conducted at the US Army Engineer Waterways Experiment Station (WES). Funding for the writing and publication of this report was provided by the Headquarters, US Army Corps of Engineers, under the Field Wave Gaging Program and the Coastal Field Data Collection Program.

This report was written by Mr. Andrew Morang at the Coastal Engineering Research Center (CERC) under the general direction of Dr. James R. Houston and Mr. Charles C. Calhoun, Jr., Chief and Assistant Chief, CERC, respectively; and under the direct supervision of Mr. Thomas W. Richardson, Chief, Engineering Development Division, and Mr. William L. Preslan, Chief, Prototype Measurement and Analysis Branch (CD-P). This report was published at WES by the Visual Production Center, Information Technology Laboratory.

The author's understanding of the subject was enhanced by many discussions with his coworkers, especially Messrs. Ralph Ankeny, James Rosati, and James McKinney (CD-P). The text was constructively reviewed by Messrs. Preslan, Joon Rhee, William Corson (CD-P), David Simpson (CR-P), and Ms. Susan Morang. Dr. Stephen P. Murray, Director, Coastal Studies Institute, Louisiana State University, Baton Rouge, LA, provided one of the examples.

An earlier version of this document was presented at the Conference and Exposition on Marine Data Systems (MDS), New Orleans, LA, April 26-28, 1989, and was published in the Proceedings of MDS '89.

Commander and Director of WES is COL Larry B. Fulton, EN. Technical Director is Dr. Robert W. Whalin.

Contents

Conversion Factors, Non-SI to SI (Metric) Units of Measurement

Non-SI units of measurement used in this report can be converted to SI (metric) units as follows:

Multiply	By	To Obtain
feet	0.3048	metres
pounds per square inch	6.894757	kilopascals

QUALITY CONTROL AND MANAGEMENT OF OCEANOGRAPHIC WAVE-GAGE DATA

Introduction

1. The processing, analysis, and quality control of directional and nondirectional wave data from self-contained oceanographic instruments are complex procedures. Quality control of each step of the data transfer and analysis is vital to ensure that the final output accurately represents the physical environment that was monitored.

2. The purpose of this report is to review common causes of data errors and to outline procedures for recognizing these errors. This report considers data analysis and quality-control aspects of processing oceanographic measurements. Neither technical aspects of the instruments nor mathematical details of the analysis software will be discussed herein.

3. The material used in this report is based on the author's experience at the Prototype Measurement and Analysis Branch (PMAB) of the US Army Engineers' Coastal Engineering Research Center. The examples that will be presented come from PMAB projects throughout the United States and the world. Much of the PMAB wave data have been collected with self-contained Sea Data 635-9, 635-11, and 635-12 gages. The examples and suggestions presented in this report are intended to be of a general nature and applicable to data from various types of wave-measurement instruments.

4. Three broad categories of problems account for most data errors:

   a. Malfunctions of the instrument during deployment in the water.

   b. Reading errors caused during data transfer to a computer.

   c. Unexpected results caused by the software during processing.

This report will discuss each of the major classes of errors and will present examples that may be helpful as other researchers are faced with similar situations.

5. A central theme of this report will be the importance of visually examining the data. The plotted data provide a vital complement to automated quality-control procedures. Sometimes, the three types of errors listed can occur in a single data set. Under such circumstances, it has been PMAB's experience that the raw pressure and directional data must be plotted and

reviewed by an analyst who is familiar with what "good" wave data should look like. The experienced analyst can then prescribe remedial action.

6. The success of the remedial action varies widely and depends on many factors such as the type of gage failure and the skill of the data analyst. As an example, at the Los Angeles, Long Beach Harbor Project, pressure and directional gages were deployed almost continuously at eight stations for over 4 years. Over 380 data sets, each representing a continuous month (a "gage-month") of data, were collected. About 80 data sets were originally flagged as being erroneous. Of these, about 40 percent were recovered, so that finally only 50 gage-months were unusable. For the whole project, this provided a data recovery rate of 87 percent.

7. Quality control and verification of wave data occurs in conjunction with data analysis. The overall processing procedure can be divided into two phases. The first phase relates to the mechanics of transferring data from the data tape to a computer and into a format that can be used by plotting programs or spectral analysis programs. Data transfer errors will be discussed in detail in this report. The second phase includes the steps used to run various computer programs and check the results. Software errors will be discussed briefly.

8. The examples in this report are based on gages that record data onto magnetic tape. At this time, instruments with internal electronic memory and internal disk drives are being tested. These will bypass most of the transfer procedures, and the data will be downloaded to a personal computer. It is hoped that most of the errors that occur in the tape recording gages will be eliminated. At this time, PMAB's experience with the electronic memory gages is limited, and it is too soon to make any conclusions about their long-term performance or dependability.

Brief Description of the Gages

9. The term "self-contained" gage, as used in this report, refers to an instrument that houses its sensing and recording systems within a package that can be deployed at sea for a predetermined time and then recovered (Figure 1). Despite the many advantages of this type of system, it has one important disadvantage: the oceanographer does not know whether the system is working properly when it is underwater. If the gage malfunctioned, there is no second

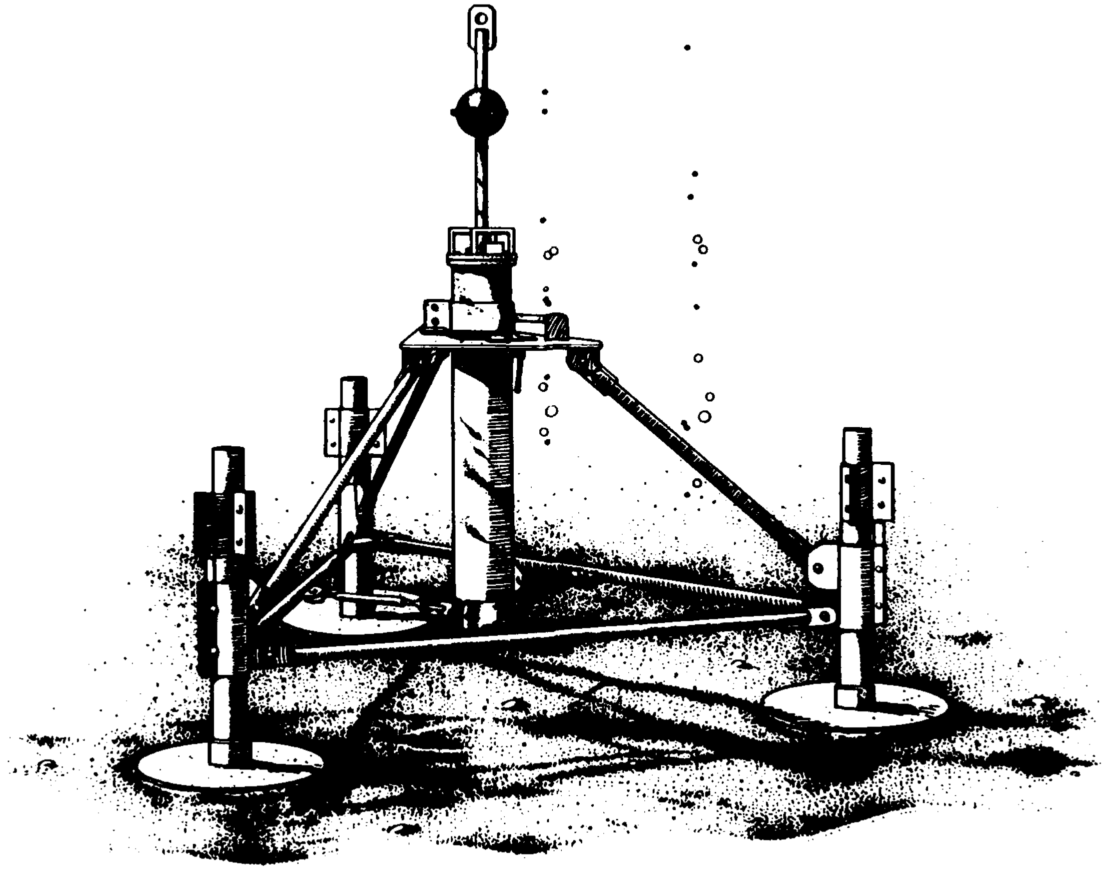

Figure 1. Sea Data 635-12, tripod-mounted directional wave gage

chance; the waves are gone. Data may also be lost if the gages are damaged or dragged away by boats or fishing nets.

10. The Sea Data 635-11 and 635-12 gages collect data in two modes: the instantaneous wave mode and the mean tide mode. The two types of measurements are recorded on the magnetic tape in different ways, and the processing software must distinguish the two. The mean mode integrates measurements over a number of minutes, usually 7.5 or 15. The 635-11 gage records a single pressure measurement for each mean interval. In addition to pressure, the 635-12 gage also measures orthogonal components of the water velocity. Therefore, the 635-12 records one pressure, one horizontal u-velocity, and one horizontal v-velocity measurement for each interval in the mean mode.

11. The other sampling mode records instantaneous values for a set length of time, which is known as a wave burst. A typical burst consists of

1,024 values recorded at 1-sec intervals, a time-series that is about 17 min long. After recording a burst, the gage waits for a set amount of time, usually 3 or 4 hr, before recording another burst. The time from the beginning of one wave burst to the beginning of the next is called the wave burst interval. The burst interval may be extended to 6 hr or more to conserve tape during long deployments. Figure 2 shows how the gage samples pressures for the set burst length and then is inactive for the remainder of the interval. The remaining figures in this report will show the recorded pressures only, and wave bursts will appear sequential, one immediately after the other. The reader must remember, however, that a significant amount of time exists between the end of one recorded burst and the beginning of the next, even though this is not shown in the plots. One wave burst will often be offset vertically from another one because of changes in the tide level (see, for example, Figures 18, 21, or 23).

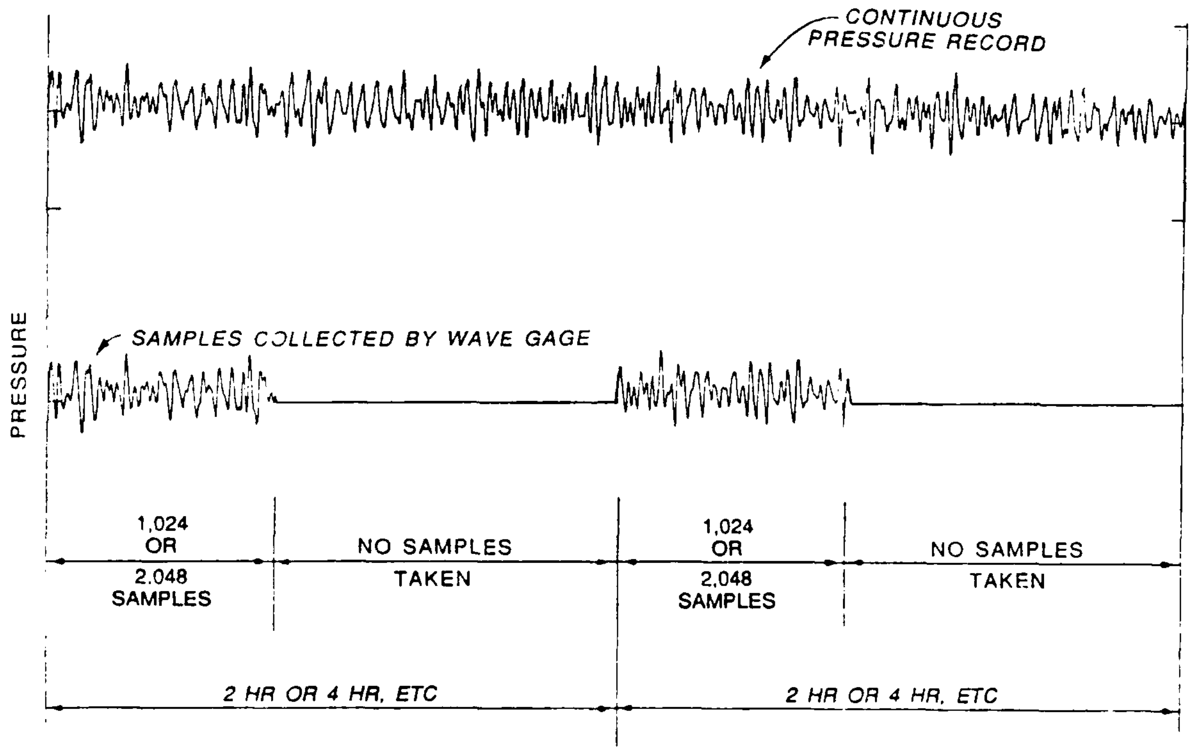

Figure 2. Wave burst sampling mode for typical wave gage

12. In the 635-9 and 635-12 directional gages, u- and v-velocities are measured and recorded at the same time as the pressures. This allows a directional spectrum to be calculated for each wave burst. The velocities are measured by a Marsh McBirney electromagnetic current meter that is mounted on one

end of the aluminum instrument housing. The Paroscientific quartz pressure sensor is contained within the housing. The pressure port is an oil-filled tube that projects from the top of the housing and serves to transmit water pressure variations to the quartz sensor.

Malfunctions of the Gage During Its Deployment

13. Of the three classes of errors, gage malfunction is the most serious, since the data may be lost or may be so scrambled that they cannot be reconstructed with confidence. This class includes two general types of errors: measurement and recording. A wave gage that performs properly must not only measure pressure and water velocity accurately, but it must also record this information onto the internal data tape in a specified format without introducing any additional errors. A gage may have produced an entire deployment of records that are physically the right length and format, but the actual recorded numbers are meaningless because the sensors or some internal circuits malfunctioned. It is normally impossible to correct this type of error. The opposite situation can also occur: the gages's sensors may have measured the waves correctly, but these data were not recorded onto the tape in the specified format. Sometimes these data can be interpreted if the error is a simple one, such as an incorrect record length. But, custom software may be necessary to read such a dataset, and the cost of this remedial work may be too high for the project's budget. The gages that record their data onto internal electronic memory appear to be more dependable than the tape recording gages and normally do not suffer from data transfer or format errors. But since PMAB's experience with the electronic memory gages is limited, further testing will be required to learn if they, too, may suffer from transfer errors under some circumstances.

14. To help reduce the possibility of gage failure in the field, meticulous maintenance and testing must be performed before deployment. Complete and accurate field notes are an important component of quality control and troubleshooting, since the deployment and recovery dates should be used to check whether or not the data sets are the right length. Examples of gage malfunctions are discussed in the following paragraphs.

15. Figure 3 shows part of a data set from a gage that performed correctly. Lines 71, 72, and 73 are mean (tide) mode records. The fifth through

```
Example of good pressure data:
==============================

71        8541

              00180  ........clock word (= 3.0 hours for this line)

                     1816911691AEEC1696AE1A169AAD56169DACAF169DAC11169CAB87

72        8540002001816 9C169CA9C7169DA943169BA8C8168DA9AA1677AC99168EAC32
73        8540002801816951695AACF1695AA611698AA041698A9B91698A975169DA935
74        858033EA33EC33EC33EC33EB33EB33EB33EC33EB33EB33EB33EB33EA33EA33E
75        858133EA33EA33EA33EA33EA33EB33EA33EA33EA33EB33EA33EA33EA33EA33E
76        858233EB33EA33EA33EB33EA33EA33EA33EA33EB33EA33EA33EA33EB33EB33E
77        858333EA33EA33EB33EB33EB33EA33EA33EB33EB33EB33EB33EA33EC33EB33E
78        858433EB33EB33EB33EB33EB33EB33EB33EB33EA33EA33EA33EA33EB33EA33E
79        858533EB33EC33EB33EA33EB33EA33EB33EA33EB33EC33EA33EB33EB33EB33E
80        858633EA33EB33EA33EB33EA33EA33EC33EB33EA33EB33EA33EB33EB33EB33E
81        858733EB33EC33EB33EA33EB33EA33EB33EB33EB33EB33EB33EB33EB33EB33E
82        858833EB33EB33EB33EB33EB33EA33EB33EB33EA33EB33EB33EA33EB33EA33E
83        858933EB33EB33EB33EA33EB33EB33EB33EA33EB33EB33E933EA33EA33EA33E
84        858A33E933E933E833E933E833E933E933E833E933E933E933E933E933E833E

85        85

             8B  ........wave line counter - from 80 to BF hex

                 33E833E933E833E833E733E833E933E833E833E933E933E833E933E933E
```

Figure 3. Examples of hexidecimal pressure data from 635-11 gages

ninth digits in these lines represent the clock word. The five-digit hexadecimal time is converted by a formula to indicate hours from reset. In this example, line 71 is 3.0 hr, line 72 is 4.0 hr, and line 73 is 5.0 hr. The other lines of data are the instantaneous (wave) measurements. In these, the third and fourth digits should represent the hexadecimal line counter. For this gage, the count begins at 80 and continues to BF, after which it rolls over and repeats the pattern.

Examples of gage malfunctions

16. Abrupt gage failure. Figure 4 shows an abrupt failure of the gage. The place where the failure occurs, line 13473, is obvious, and the remainder of the data set can be discarded. The data immediately preceding the failure should be examined for any deterioration that might have occurred. Unfortunately, most gage electronic failures are not as obvious. The following examples will demonstrate more subtle problems.

17. Wave counter did not record on the tape. Figure 5 is an example of a data set in which the counter did not work correctly. It can be seen that only 80 or 81 were recorded. These data can be saved by having a counter in the software that keeps track of the pressure values and counts them to be

```
13450    85B0D06DD0B2D13AD1B1D205D15BD024D083D1C2D25DD17DD05CD07FD196D1CED124FA
13451    85B1D0D9D12BD14FD136D179D1A6D0E9D0ABD143D169D17CD184D0C2D093D1A4D24BF5
13452    85B2D136D013D0A0D208D24DD11DD054D0AED168D1CED171D0F2D119D146D0E4D06EF2
13453    85B3D11AD262D21CD094D004D0C4D1E3D23CD144D05AD0B8D191D1A5D14DD141D105F9
13454    85B4D0A7D110D1E1D1ABD0C0D0AED151D185D141D10FD132D14AD118D0F4D10AD183FA
13455    85B5D1E4D11BD03FD0E4D1DCD1DED0D6D06FD145D1C8D122D100D182D135D084D124FA
13456    85B6D212D178D05CD097D1ECD25ED072CFA1D1B9D360D1AECFB0CFDCD1B3D29DD1A9FB
13457    85B7D077D060D150D221D184D01BD08CD251D22AD098D072D157D176D147D145D118FD
13458    85B8D104D13FD132D11CD14FD115D0C1D10FD1B3D1FBD115CFDBD093D287D28DD0D1F6
13459    85B9D04ED11BD150D0F5D15CD1C7D162D0B7D0ACD149D1E1D133D0A6D144D1C4D139FC
13460    85BAD0D4D0ECD13FD158D137D119D182D1B2D0C9D026D0D4D22DD23FD115D044D0A1F1
13461    85BBD179D1E6D1A6D0E6D0C5D0F7D116D16AD162D124D12ED15AD14FD0CAD094D163FD
13462    85BCD21CD19BD0ADD0DBD151D0EDD0F4D1B9D1EFD0FDD060D10BD1AFD16FD0EDD0DAF2
13463    85BDD105D120D18CD197D0E4D09ED136D173D144D140D11BD104D16CD14AD086D124F0
13464    85BED226D160D061D08DD176D228D19BD062D082D19DD1E6D127D0A8D0E5D16DD1B8FA
13465    85BFD15BD0A5D0ACD150D17BD192D19BD0B7D042D0ECD1F7D274D177D013D040D184F8
13466    8541118B017BFDABFD9CB6BBFEFCB6CBFF9CB6CBFE5CB6CBFE2CB6FBFE2CB6FFFFFFF3
13467    8540118E017BFF6BFF6CB70C009CB73C00BCB75C018CB79C00FCB7FC015CB86FFFFFFE
13468    85401191017C010C010CB8EC001CB94C005CB9DC007CBA6C009CBABC018CBB4FFFFFF7
13469    85401194017C034C034CBBAC045CBC0C057CBC4C060CBC7C071CBCAC087CBCDFFFFFF9
13470    85401197017C08BC08BCBCDC08ECBCDC096CBCEC0A1CBCEC099CBCDC0AACBCCFFFFFFC
13471    8540119A017C0B7C0B7CBCCC0B7CBC9C0B6CBC9C0BCCBC7C0BECBC6C0C8CBC6FFFFFFE
13472    8540119D017C0CEC0CECBC5C0D4CBC6C0C7CBC7C0D6CBC8C0D8CBCBC0D8CBCEFFFFFF5
13473    75FFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFF
13474    75FFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFF
13475    75FFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFF
13476    75FFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFF
13477    75FFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFF
13478    75FFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFF
13479    75FFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFF
13480    75FFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFF
13481    75FFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFF
13482    75FFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFF
13483    75FFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFF
13484    75FFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFF
13485    75FFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFF
13486    75FFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFF
13487    75FFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFF
13488    75FFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFF
13489    75FFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFF
13490    75FFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFF
```

Figure 4. Data from a gage that abruptly failed at line 13473

sure that the correct number, often 1,024 or 2,048, have been recorded. As the points are counted, the time is incremented and compared with the time word that is written onto the tape by the internal clock of the gage.

18. <u>The clock did not record on the tape.</u> If the clock malfunctions, the data can be used as long as the wave counter has correctly recorded. The processing software must count the pressure points and increment a time counter. It must then compare the calculated time with the beginnings and ends of wave bursts that occur at predetermined intervals. If the times do not match, the software must determine where there are missing points. If the gage counter has not recorded properly, the analyst must assume that each measured value was recorded. This assumption can only be verified if a comparison is made with data from a nearby gage.

19. Figure 6 shows data in which neither the time nor a line count was written. The third and fourth digits are not sequential from line to line,

Example of pressure data with faulty wave line counter:

```
 990    8581A81AA81BA816A819A81EA818A812A817A819A813A812A817A816A811A81
 991    8580A811A80FA816A818A812A817A81CA817A812A816A818A812A813A817A81
 992    8581A818A819A815A813A817A816A811A815A819A810A810A81AA819A812A81
 993    8580A816A815A81BA816A810A815A819A815A812A819A819A818A818A817A81
 994    8581A81BA81AA816A81AA81CA817A816A819A817A816A819A81AA817A817A81
 995    8580A817A819A81DA81CA819A81BA81CA816A816A81CA81BA817A818A819A81
 996    8581A81AA816A817A819A817A815A818A818A815A817A81BA819A815A818A81
 997    8580A817A81AA81DA81BA815A815A817A817A818A81BA81DA81BA81AA81AA81
 998    8581A81AA818A81CA81FA819A81AA819A817A818A81AA819A819A817A818A81
 999    8580A815A819A81BA818A815A817A819A818A81AA81FA81EA81CA820A81EA81
1000    8581A81DA818A816A81AA81CA81BA81FA824A81FA81AA81EA81DA81CA81EA82
1001    8580A81DA81BA81DA81DA81AA818A81CA81CA81BA819A81CA81FA81EA81EA81
1002    8581A818A816A817A81BA81EA821A820A81CA81BA819A81BA81BA81AA818A81
1003    8580A816A816A81FA81EA817A818A819A814A819A823A81DA812A815A81FA81
1004    8581A81BA81AA819A820A820A817A814A817A81BA81CA81CA817A816A81AA81
1005    8580A81AA818A81AA81DA819A815A81DA81FA818A814A819A81DA81BA81AA81

1006    85

          81  ........counter only recorded 80 or 81

          A815A819A81AA818A813A80FA816A820A81BA80DA810A81FA820A815A81
```

Figure 5. Pressure data from a malfunctioning gage that did not increment the wave line count

Example of data with no clock word or line counter:

```
60    75FBE7450B6FF890B65099F7750B7FF990B65449FF750BAA7800B5744AAB6F8
61    75EAF6650BAEF090B65408FF750BAAF910B65448FF650BBA4450B6FF4B8B6F8
62    75925019E4550B7FF990B75099FF650BAAF010B7F549EF65088E4450B6FF000
63    758AF4450B6FF880B55099FF750BAAF910B65449EF650AAE4050B5FF0BAB6F9
64    75BBFE650BAEF990B65448FF650BAAD990B6FD4AEF65088E4450B6FF080B7FF
65    75AAF6450BAAF810B7544AFF550BBA5450B6FF4BAB65088F4650BEFFAA0B7FD
66    759AF7750BAEF010B65448FF7509BA4050B6FF4AAB75099E4650B6FF090B6FE
67    756F7FC808000DDF5B139D00B15F40B115F208AEE12FF44DBAFF4EF900FFFF6
68    758AFF550BAAF010B5544AFF6509BE4450B6FF880B65489FF650BAAF190B66E
69    7533A4450B7FF8A8B75099F6450BAAFA00B65449AB650BBE4450B6FF88AB5F2
70    752AFB650A8AF550B6FF490B55099FF650BAAF880B6544AFF65088E4450B6FF
71    75BAA4150B6FF8AAB65099F7650BAAF880B65449EF6509BA4450B6FF8A8B6F2
72    7542FE650BAAFAA0B6FF4AEF6509BA4550B6FF080B75409FF650BAAD090B6DB
73    75BBAF050B5FF0AAB650AAF4650BEFF990B6544BFF6509BA5450B7FFAB0B7F6
74    75BD50AAF6650BEEF990B65449EF650AAA44D0B6FF4AAB65099E5550BAEFAA5
75    751BAF450B6FF4A0B65099F7550BAAFA00B75449FB6509BE4450B6FF992B6F5
```

Figure 6. Data from a malfunctioning gage that did not record a clock word or a wave line counter

and there is no obvious time word. Analysis of these data is not possible since it is unknown where each wave burst began or if all the values from each burst were recorded.

20. A listing or a summary of the erroneous records and locations where the counter has jumped is a necessary part of the quality control during data processing. Figure 7 is an example of a diagnostic message from the PMAB engineering conversion program that lists where missing lines have been detected. If the processing software can keep track of these locations, the missing data values can be estimated possibly with a linear interpolation method. Otherwise the waveforms will have abrupt jumps that will cause errors in the Fourier Analysis. If too many lines are missing, the analyst must decide whether or not the data set can be spectrally analyzed. The acceptance threshold may vary from project to project depending on economic and scientific factors.

21. Cassette tape is blank. Numerous electronic and mechanical problems could account for this. It is important that the battery voltages be checked before deployment to ensure enough battery capacity for the anticipated deployment. An unusual mechanical problem that sometimes occurs is that a new tape will not advance even though there is no visible evidence that the housing is warped or that the tape has more friction than usual. This can usually be prevented by advancing and rewinding the tape before it is installed in the gage. If there is any doubt whatsoever about the mechanical condition of the tape, it should not be used.

22. Failure of the tape drive or a problem such as flat pinch rollers. Usually the data are useless. This also underscores how vital it is to perform meticulous maintenance before each deployment. If in doubt, all the rubber components and belts in the tape drive should be replaced.

23. Failure of one or both axes of the electromagnetic current meter. The directional data are not usable, but that does not affect the pressure values.

Environmental hazards

24. Pressure port plugged with silt or debris. Low frequency pressure variations are recorded, but all the higher frequencies are filtered out. This is often a problem in harbors where the ships' screws churn up the bottom, in estuaries where there is high organic growth, and off river mouths, especially during a freshet. Identifying this type of problem can be

CLEVELAND BREAKWATER, OUTSIDE SITE
GAGE 39, JULY - SEPTEMBER 1981

WAVE COUNTER JUMPS   E - EXPECTED COUNT   F - FOUND COUNT   REC # - INPUT RECORD NUMBER

REC #	E	F	REC #	E	F	REC #	E	F	REC #	E	F	REC #	E	F	REC #	E	F	REC #	E	F	# JUMPS
1040	33	34																			1
17024	4	5																			1
23491	39	40																			1

CLEVELAND BREAKWATER, OUTSIDE SITE
GAGE 39, JULY - SEPTEMBER 1981

TIDE TIME JUMPS   E - EXPECTED TIME   F - FOUND TIME   REC # - INPUT RECORD NUMBER

REC #	EXPECTED	FOUND	REC #	EXPECTED	FOUND	REC #	EXPECTED	FOUND	REC #	EXPECTED	FOUND
334	1861.500	1862.500	38123	3554.500	3555.500						

Figure 7. Example of diagnostic message produced by PMAB processing software

difficult. This is illustrated by a comparison of pressure data from two gages deployed at the mouth of Mobile Bay, AL. In Figure 8, the upper plot is from the plugged gage; the lower one from a correct gage. This view of the entire data set suggests that both gages were operating properly since both recorded the tidal (low-frequency) variations. Yet, the upper curve is thinner than the lower, suggesting that the upper gage measured less high-frequency variation. This is the clue that individual wave bursts should be examined in more detail. When 1,024 points are plotted on one page (Figure 9), it becomes evident that the amplitude of the pressures measured by the first gage is much lower than that of the second. But, without comparing data from a second gage, it might have been difficult for the analyst to conclude that the pressures from the first gage were unreasonably low. The diagnosis could be especially problematic in a location like the Gulf of Mexico, where low waves often occur for long periods.

25. Figure 8 also demonstrates an environmental hazard that can affect a project: the abrupt increase in mean pressure that occurs near the end of the data set marks the time when a fishing boat knocked the tripod on its side and damaged both gages. Fortunately, at this site, the gages were recovered and the data tapes were intact. Occasionally, the gages are dragged away and lost forever.

26. Data from a plugged gage are difficult or impossible to reconstruct. In addition to the pressures being too low, the values are also shifted in phase. To reconstruct the data, both phase shifts and amplitude multiplication factors have to be applied to the different frequency bands.

27. Marine growth over the pressure port. The gage will perform properly when it is first deployed, but accuracy will progressively deteriorate. Eventually, the high frequencies will be damped out and the data will resemble that from a plugged port, as illustrated in Figure 9. The analyst must decide how much of the data set is realistic and valid for spectral analysis.

28. Marine growth over the electromagnetic current sensors. Here too, the data quality progressively deteriorates, and the analyst must decide how much of it can be used. The rubber ball that forms part of the Marsh-McBirney electromagnetic current meter is impregnated with an antifouling chemical. This chemical should remain active for about 1 year. Since marine growth can occur very quickly in some areas, an old sensor should not be used unless the experiment is of very short duration, such as 1 or 2 weeks.

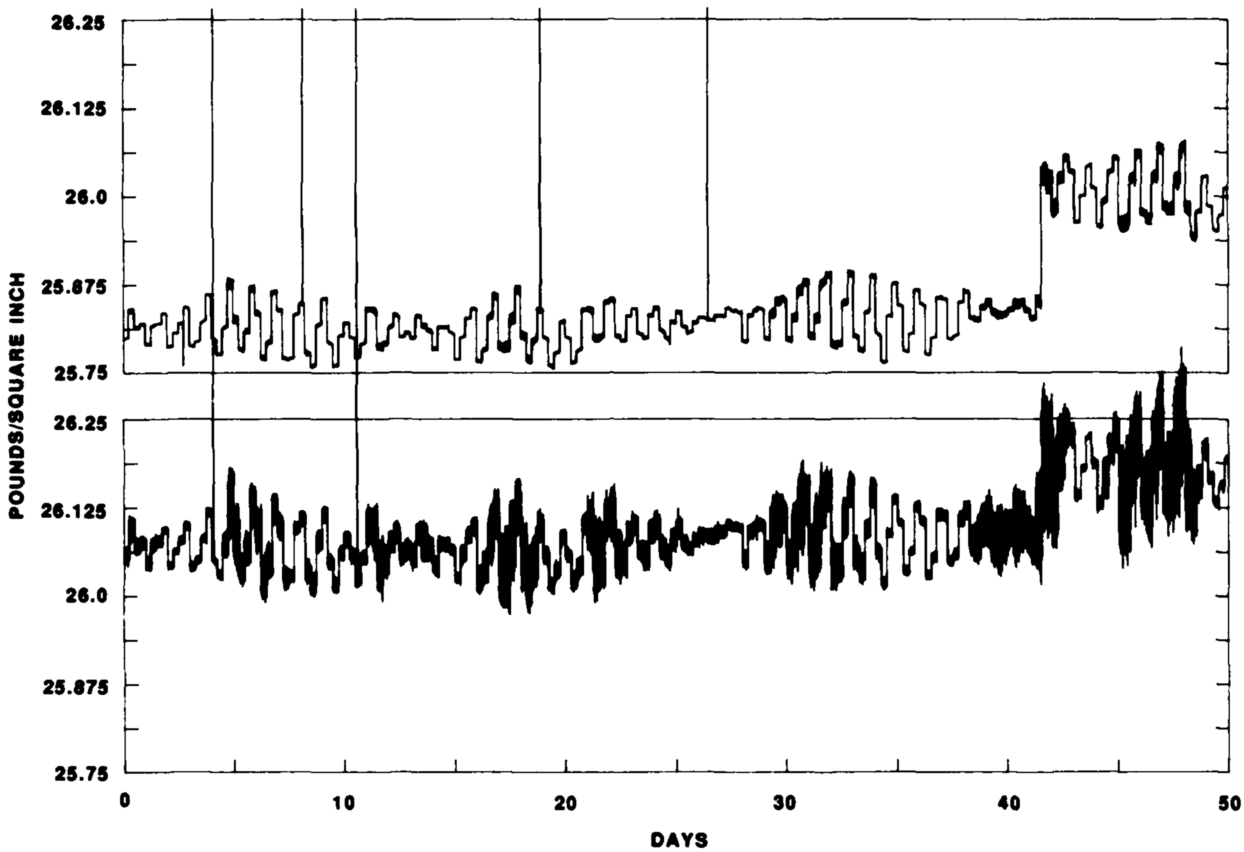

Figure 8. Pressure data from two gages deployed at the same site. The upper curve is from a gage with a plugged pressure port. The plugged gage was mounted on a higher position on the tripod, which accounts for the slightly lower mean pressure that it recorded

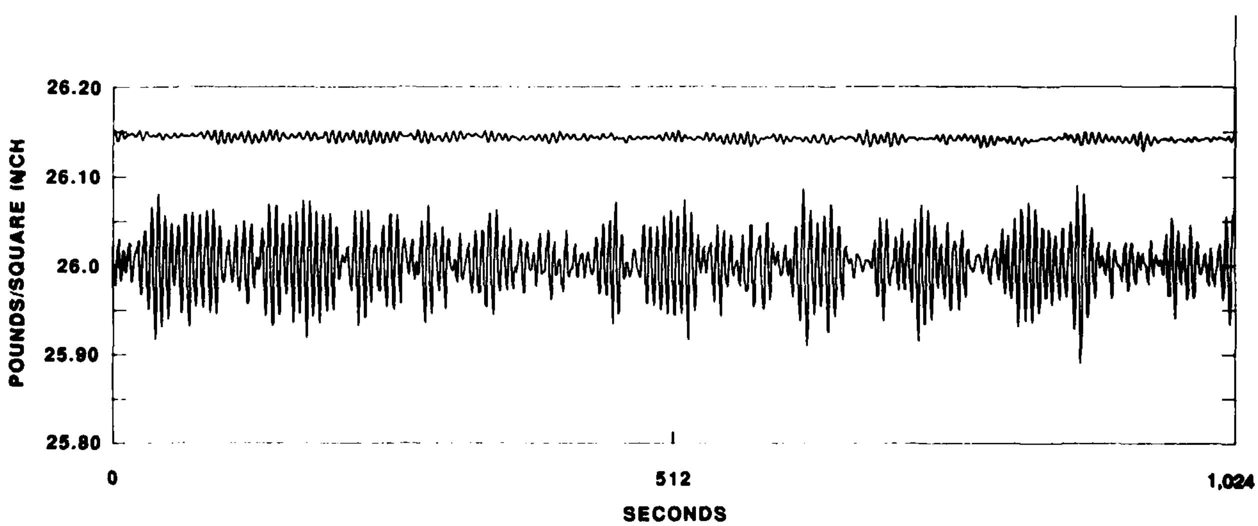

Figure 9. Comparison of a single wave burst (1,024 points) from two gages deployed at the same site. The upper curve is from a gage with a plugged pressure port

Unusual gage failures

29. The mean data (tide measurements) show an odd jump every six measurements. This problem may be unique but is included since it illustrates the types of procedures the analyst must follow when confronted with inconsistent data. The software diagnostic showed that there were time jumps throughout the data set. The gage collected six tide pressure samples and wrote these on the cassette tape, but the clock behaved as if eight samples had been collected on each line of data. The analyst must ask: did the gage not record the last two measurements, causing a gap after each six values? Or, should the six measurements be evenly spread out over the time that should have included eight? A sampling rate of 3.75 min was set on the instrument when it was deployed. Therefore, for six samples, each line of data should equal 22.5 min, yet the clock recorded 30.0 min for each line. Six evenly spaced values would indicate an interval of 5.0 min per sample, a switch setting that is not an option with this type gage. Electronic tests of the gage revealed that it had actually not recorded the last two values. Figure 10 illustrates the way the data were recorded.

30. Wave burst was not recorded continuously. In this example, 1,024 points were sampled at 0.5 Hz and should have produced a record that was 8.53 min long. But yet, a careful examination of the individual wave bursts revealed that an anomalous jump occurred after each 64 points. This is best shown in a plot in which the unconnected points are plotted adjacent to the curve (Figure 11). The vertical lines indicate where the wave form is discontinuous. It is not possible to know how much time is represented at each discontinuity: it could be only a few seconds or many minutes. This problem may also be one that was unique to a particular gage, but it illustrates how a very detailed graphical examination of the data is sometimes necessary.

31. Full wave burst of 1,024 points was not recorded. Figure 12 shows a data set in which only about 925 points were written to the tape for each burst. The amount of lost data was different from burst to burst. To use these data, it was possible to perform spectral analysis by segmenting the data and discarding the last segment.

32. Figure 13 is an example of a data set in which each wave burst was exactly 1,008 points long rather than the 1,024 originally set. Sixteen values were missing because the gage failed to write the last two lines of hexadecimal code of each wave burst on the magnetic tape. A check of the field

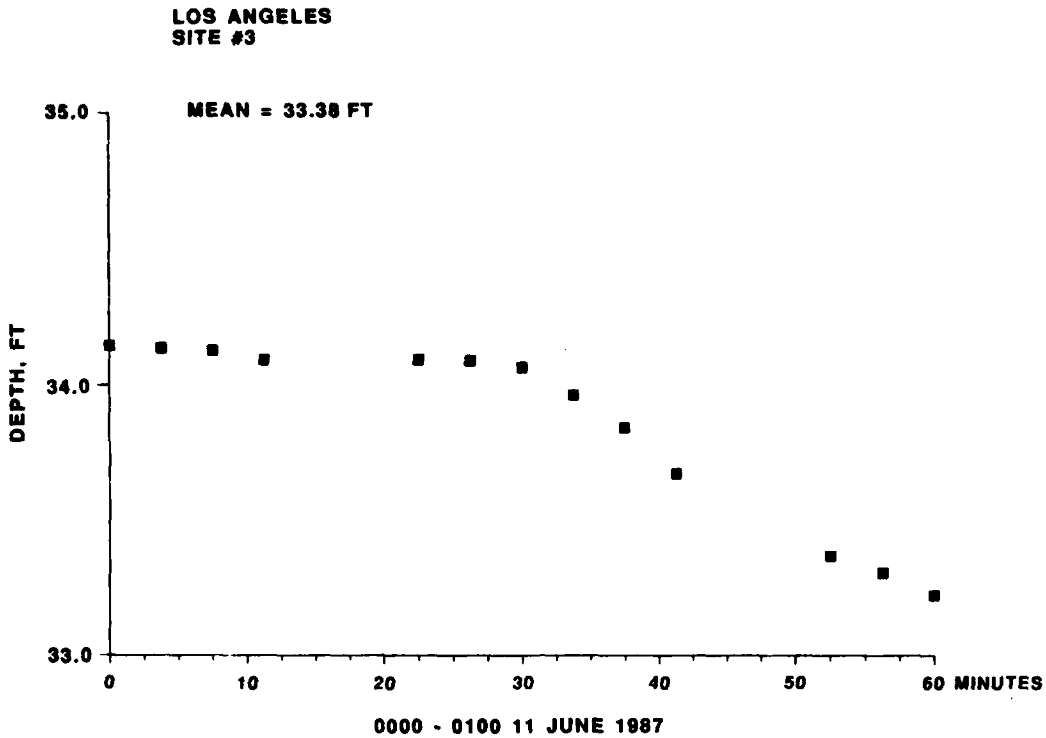

Figure 10. Data from a gage that recorded only six data points, while the clock advanced as if eight had been recorded

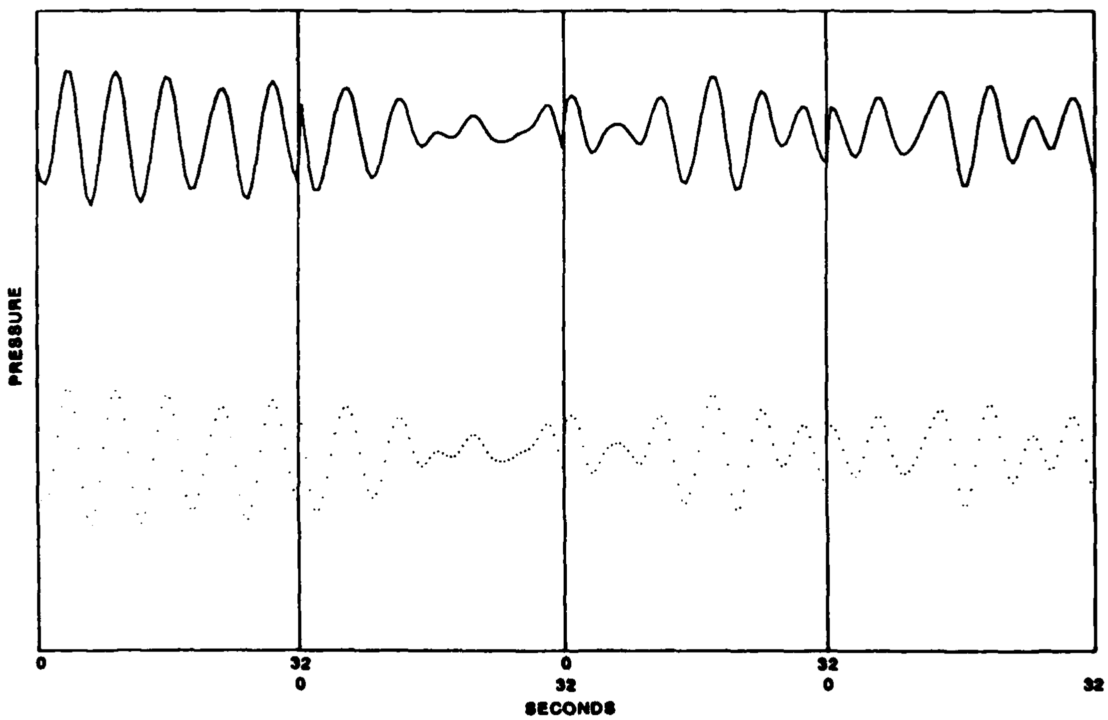

Figure 11. Data from a gage in which the wave burst was not sampled sequentially for 1,024 points but rather in groups of 64 points, each separated by an unknown amount of time (Data provided by Dr. Steven P. Murray, Louisiana State University)

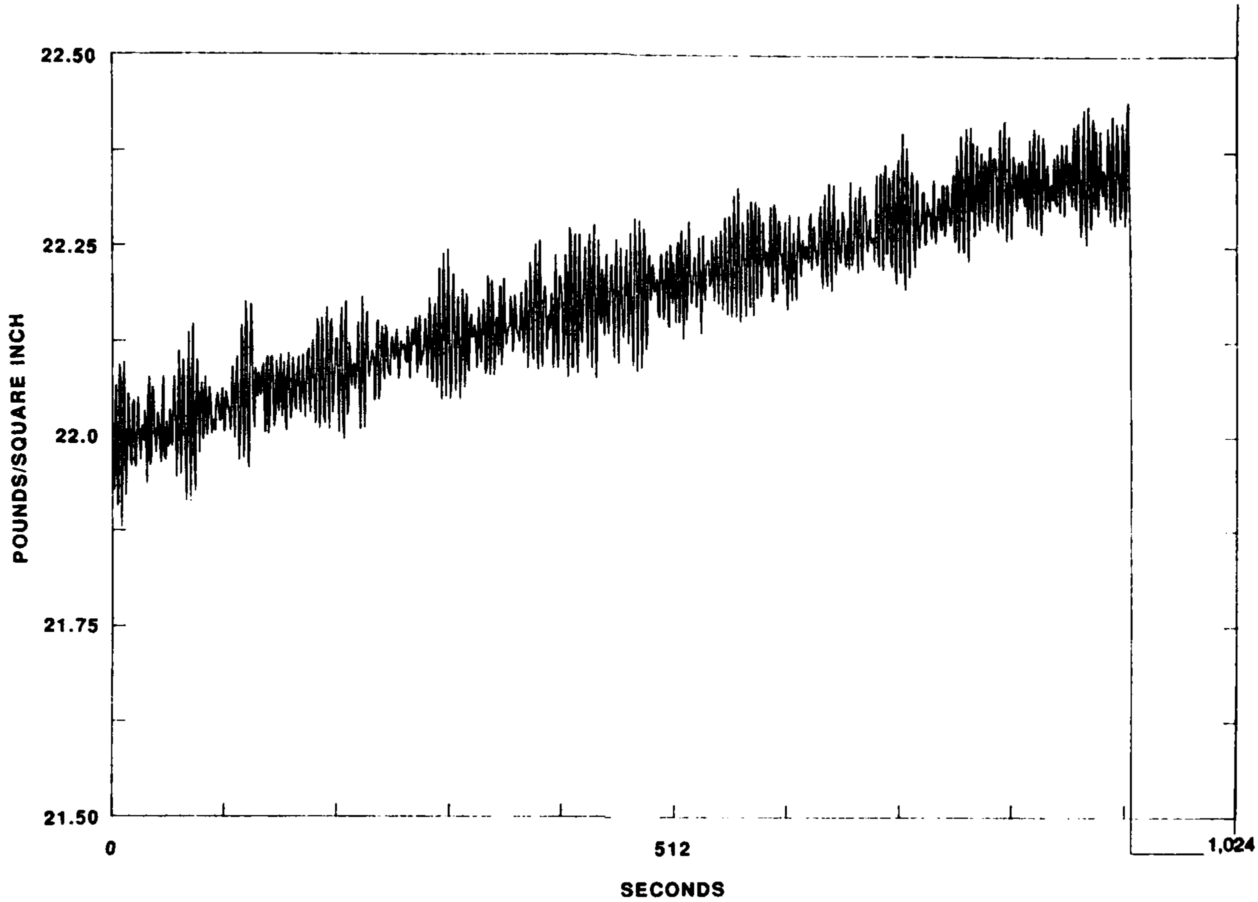

Figure 12. Pressure data from a gage that recorded approximately 925 points rather than the 1,024 set on the instruments. The plot should continue to the right margin. The steep slope of the curve represents a rapid increase in water level from the incoming tide

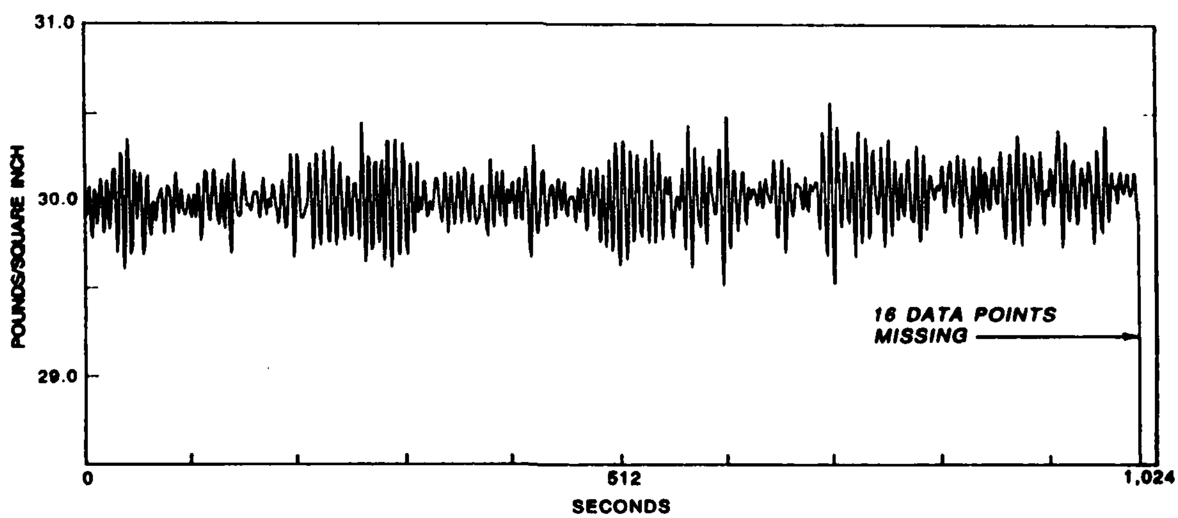

Figure 13. Pressure data from a gage that did not record 16 points, representing two lines of hexidecimal code from each 1,024-point wave burst. Plot should continue to the right margin

notes revealed that the gage had been set on a very rapid mean data (tide mode) sampling rate of 64 samples per hr (one value every 0.938 min). Although the exact cause of the failure was never identified, it appears that the buffer in the gage storing the wave data was unable to dump its contents fast enough to the tape. As the tide measurements accumulated, the last 16 wave samples were erased before they could be written onto the tape. This 635-11 gage had never been tested at these settings, although it had performed perfectly when a slower rate of 32 samples per hr was used. This example illustrates the importance of thoroughly testing the instruments before a deployment.

Errors in Reading the Data Tape

33. Transferring data from tape to the user's computer would seem to be a relatively simple procedure, but many errors can result from the way the tape reader reads the tape and interprets bad records.

Specific examples of reading errors

34. The tape has been wrinkled or bent. Wrinkling or bending of the tape can occur when the cassette is not properly seated in the tape drive of the gage. If the tape is flat as the data is written to it, it can probably be used. But if the tape wrinkles before it moves past the tape heads, the data set most probably will be useless. When the tape is read, the channel closest to the wrinkled section will vary widely in gain, because the tape will not be touching the head with uniform pressure. A possible solution is the tape can be wound and rewound several times to try to flatten it and make it spool neatly. This again emphasizes the importance of setting up the instrument with great care before its deployment.

35. Errors in reading the tape with no obvious cause. Occasionally, grit or residue is deposited quickly on the heads of the tape reader. This can be a problem even when premium quality data tapes have been used. A possible cure is to clean the heads frequently with alcohol swabs. Figure 14 is an example of data with many noise spikes. The second transfer, after cleaning the heads, produced a much cleaner data set (Figure 15).

36. Errors in reading the tape, when the heads have been cleaned. Some heads are longlasting, but some wear out in only a few months. Even though the head does not look scored or ridged, it may be worn unevenly enough not to

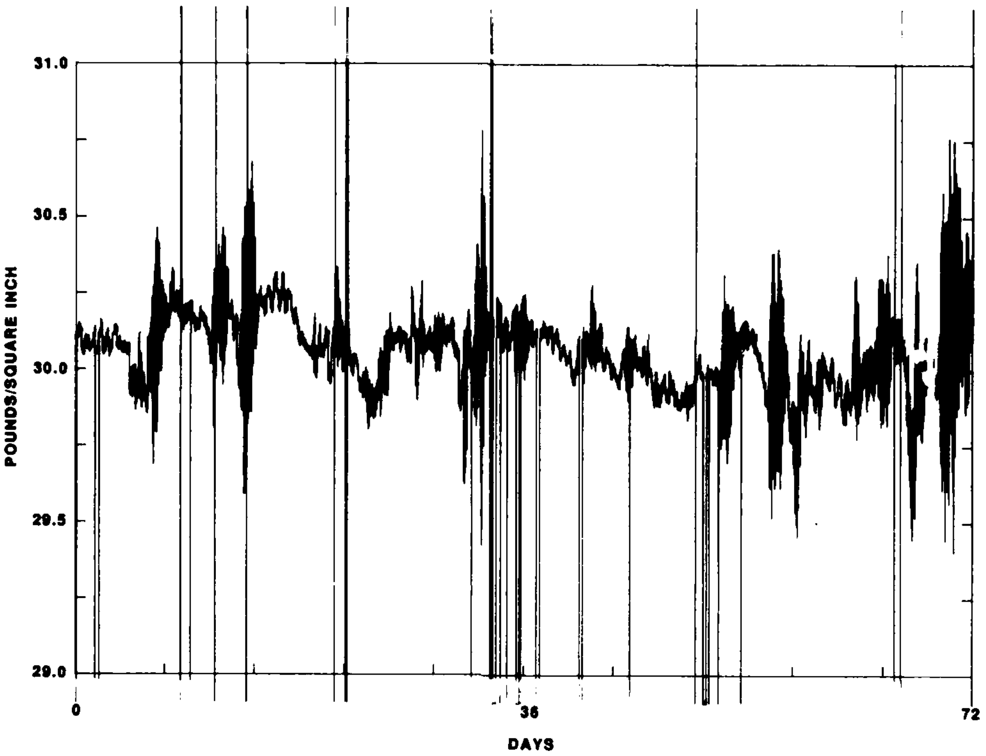

Figure 14. Example of a data set with numerous noise spikes

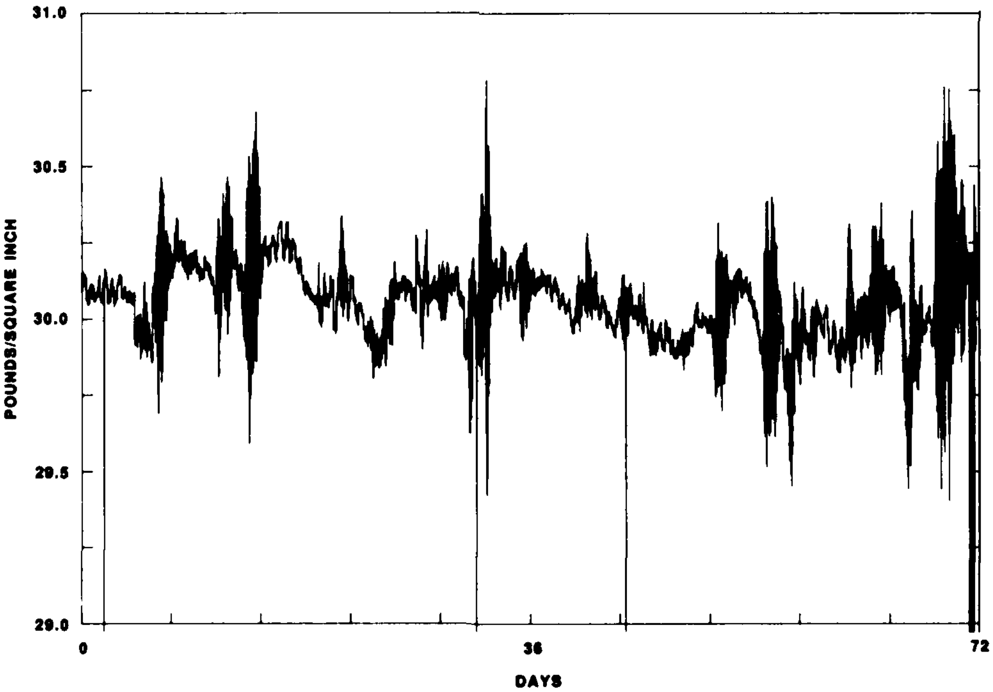

Figure 15. The same data set shown in Figure 14, but retransferred after the tape reader heads had been cleaned and adjusted. The result was much cleaner

maintain constant contact with the tape. A possible cure is to replace the head assembly in the tape reader.

37. Regularly repeating pattern of parity errors and short records. One of the pinch rollers in the gage's tape drive might be flat and need to be replaced. The data probably cannot be saved if this has occurred. As stated earlier, checking the condition of the rubber parts of the tape drive is a vital aspect of the gage checkout.

38. The tape drive in the gage in perfect operating condition when deployed, but data tape developed many errors. Was the project site in cold water? Tapes are available from Verbatim Company specially designed for use in cold conditions. Also, cold-deployment pinch rollers are available for the Sea Data instruments. They are an option to consider, especially if the gages are going to be used in Alaska or in the Great Lakes during the winter.

Data repeat errors

39. Data file is too long. A full Verbatim tape recorded on a Sea Data instrument contains about 52,000 lines. If, after a transfer, the file has more than this number of lines, the tape reader must have reread a section of the tape. This can occur if the data set contains bad lines and the tape reader detects parity errors. In normal operation, the reader fills a buffer with data from the cassette tape. These data are then sent on to another device, and the buffer is ready to be refilled. The tape is rewound slightly and reread, and the results are compared with the contents in the buffer so that only new data are stored. If the parity errors occur in the section of the tape that is reread, the instrument may be unable to make a comparison, and the buffer may be filled with data that have already been read. Sometimes, the tape rewinds to the beginning as the reader searches for the same data that are in its buffer.

40. There are two solutions to this problem: (a) retransfer the tape after cleaning the heads, winding and rewinding the tape, and making sure that the gains are adjusted correctly (Often this second transfer will be successful.), and (b) edit the raw hexadecimal data file manually using the editor on the computer. Sometimes it is quite easy to find the location of the data repeat, and the superfluous lines can be deleted. The easiest identification occurs when the time word shows an obvious jump backward compared to the previous lines. If the data file is very clean, the detective work is more labor intensive, and the time records throughout the entire file have to be

methodically reviewed to try to find where the backward jump occurs. In this situation, it is probably better to first try to reread the tape after cleaning the heads and checking to be sure that all the transfer procedures have been followed properly.

41. Data repeat occurs in a short data set. If the gage has been deployed for only a short time, the count of the total number of lines will be less than what a data tape is capable of holding and, therefore, will not reveal whether or not any of the data have been reread. This type problem may become evident only when the pressures are plotted and an anomalous jump can be seen. Figure 16 illustrates a data repeat that became obvious only after the spectral analysis had been performed, and the energy density was plotted.

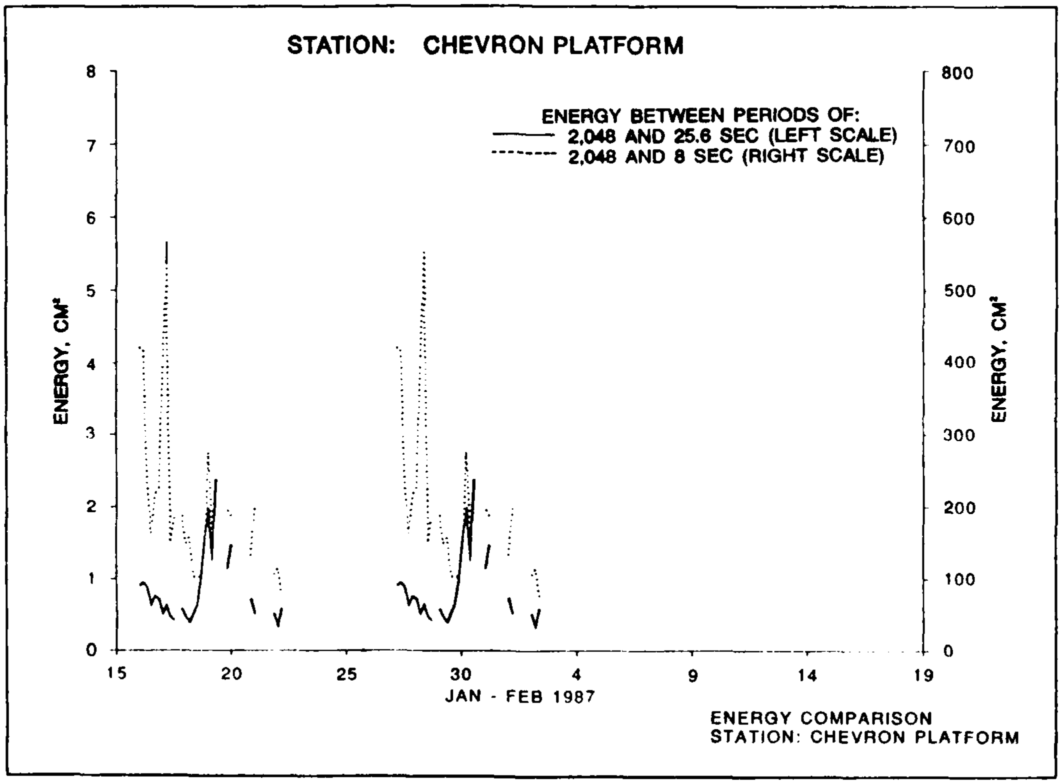

Figure 16. Example of a data repeat that occurred when the tape reader encountered bad records

42. The gage recovery time recorded by the field technicians does not correspond to the time shown by the processed data. The times should match within a few hours, even after a deployment of many months. This problem must be approached from two directions: first, the field notes must be checked; and second, the data transfer and the processing software must be checked. If

the time discrepancy is 24 hr, this is often a clue that the wrong day was recorded on the log. Usually, the problem is caused by a data or processing error, and the analyst must first check whether a data reread has occurred. If a reread does not prove to be the reason for the time discrepancy, the data may have some bad segments and the software has been unable to compute the times properly because the wave bursts are missing lines. This will be discussed in more detail later.

Software and Processing Errors Caused by Extreme Conditions

43. Processing and analysis of wave data must be careful and methodical. The computer programs that convert the raw data to engineering units, print and plot the results, and perform spectral analyses are complicated. They must be run with as much consideration toward quality control as the other aspects of the project. Software problems are frustrating, insidious, and difficult to detect. Fortunately, they usually can be isolated and solved. It is beyond the scope of this report to delve into the software code of the various analysis programs, but this section will describe some of the typical problems that can occur and will suggest general solutions.

Data spikes

44. Spikes in the data. This is a common problem. Before the analyst performs any filtering or manipulation of the data, he must decide if the spikes really came from the gage or if they are artifacts of the transfer procedure or the software. The first phase of troubleshooting should be to transfer the data again from the data tape to the computer. As discussed previously, this can often improve the data.

45. Gage malfunctions. If the instrument has malfunctioned, the analyst must decide how many bad points can be tolerated in a data set and how many can be replaced with ones generated by an interpolation or statistical procedure. Efforts to repair a data set with numerous errors can take considerable time; the project's budget may dictate whether the data set is to be repaired or simply discarded. Sometimes, a critical set of measurements, such as those obtained during a hurricane, may necessitate salvaging regardless of the time required for the repair efforts.

46. Spikes in the data caused by high energy. Sometimes, spikes may actually represent the waves that occur at the field site. The analyst must

be aware of the physical environment where the instrument has been deployed when he evaluates the data. In some locations, such as in Lake Michigan, the wave energy can vary dramatically in only a few hours (Figure 17). In this example, the lake has changed from being almost calm on April 5 to having waves nearly 4 meters high only a few hours later. An analyst who is not aware of these violent storms might erroneously conclude that the gage has malfunctioned. A plot of the pressures proves that the gage has measured a tremendous increase in energy levels in only 6 hr (Figure 18).

47. Figure 19, showing energy at Station 2 at Long Beach Harbor, CA, illustrates another example of unusual conditions. These data appear to be erroneous, and a plot from Station 1, only a few hundred meters away, shows much lower energy at this same time (Figure 20). But a detailed comparison of the pressure data (Figure 21) reveals that the energy at Station 2 was significantly higher at certain times. The upper curve in Figure 21 is pressure from Long Beach 1, and the lower curve is Long Beach 2. The vertical shifts represent water depth changes because of the tide. The lower plot shows that the energy at Long Beach 2 increases manyfold in only a few hours and then decreases. The cause of the unusual pressure changes is unknown but may be related to harbor oscillations or some other hydraulic mechanism.

Unrealistic magnitudes

48. The magnitudes of the recorded pressures are unrealistic. Possibly the wrong calibration coefficients have been used. The Paroscientific pressure transducers are calibrated by the manufacturer, and each sensor has unique coefficients. Other types of pressure sensing devices must be calibrated by the user. Ideally, these sensors should be checked before and after the field deployment. There is no perfect calibration of a device like a pressure gage, and details of the different procedures are beyond the scope of this report. Generally, the manufacturer's instructions must be followed rigorously and consistently.

49. Overall magnitudes of the orbital velocities are much too high. For Sea Data instruments, this problem may be caused by an error in the software that unpacks the raw, hexadecimal data. To conserve space, the 10-bit current measurements are represented by the 8 least significant bits. In the computer program, the wave data must be followed sequentially, and 256 units must be added or subtracted if the velocity goes below or above 00, respectively. In a 635-12 gage, the reconstructed velocities can be compared with

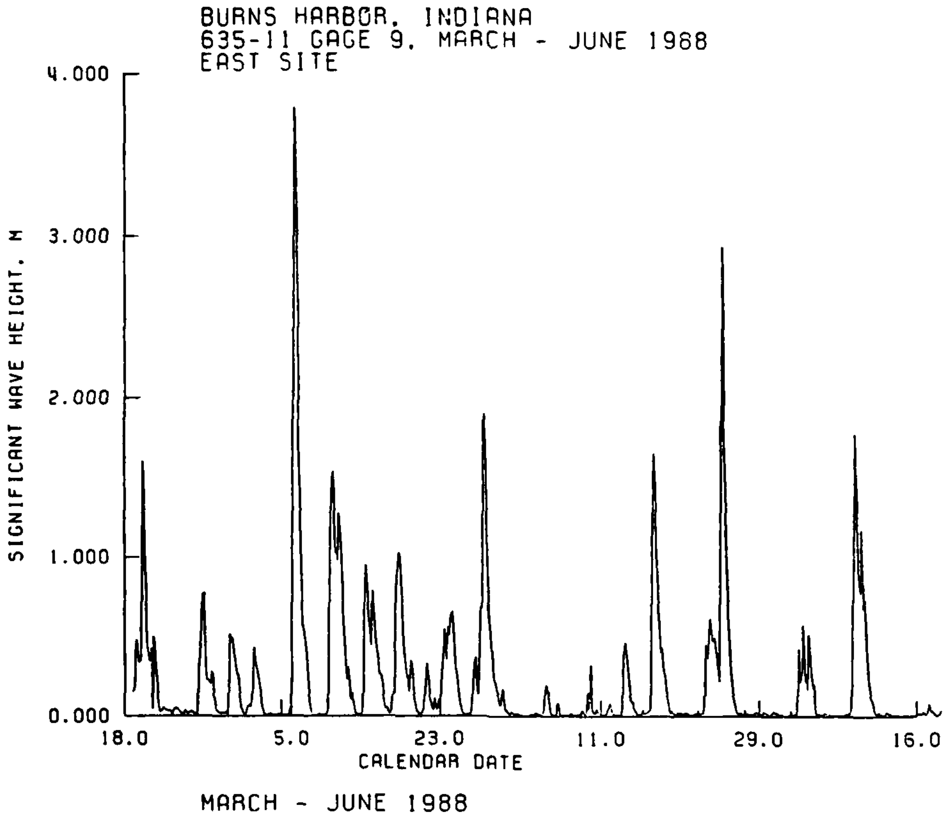

Figure 17. Wave energy from southern Lake Michigan. The peaks demonstrate that the waves can change dramatically in only a few hours

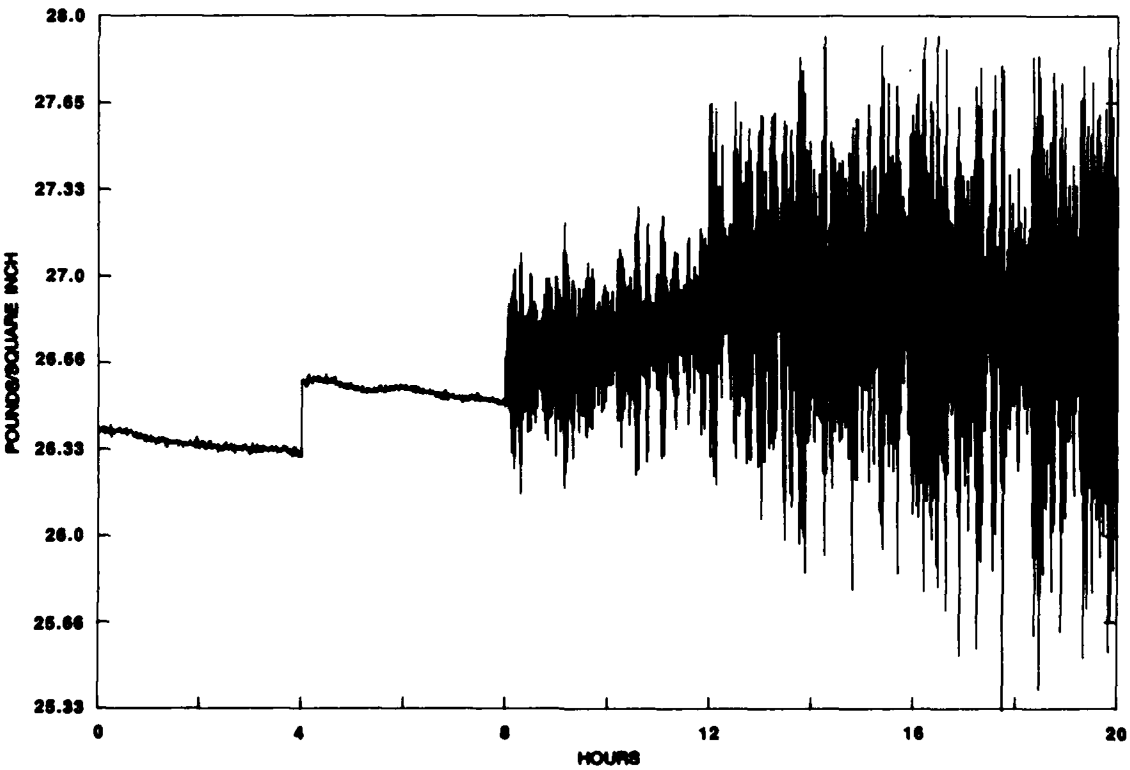

Figure 18. Pressure time-series plot from the same site in Lake Michigan as Figure 17, demonstrating the tremendous increase in energy in only a few hours during April 5, 1988

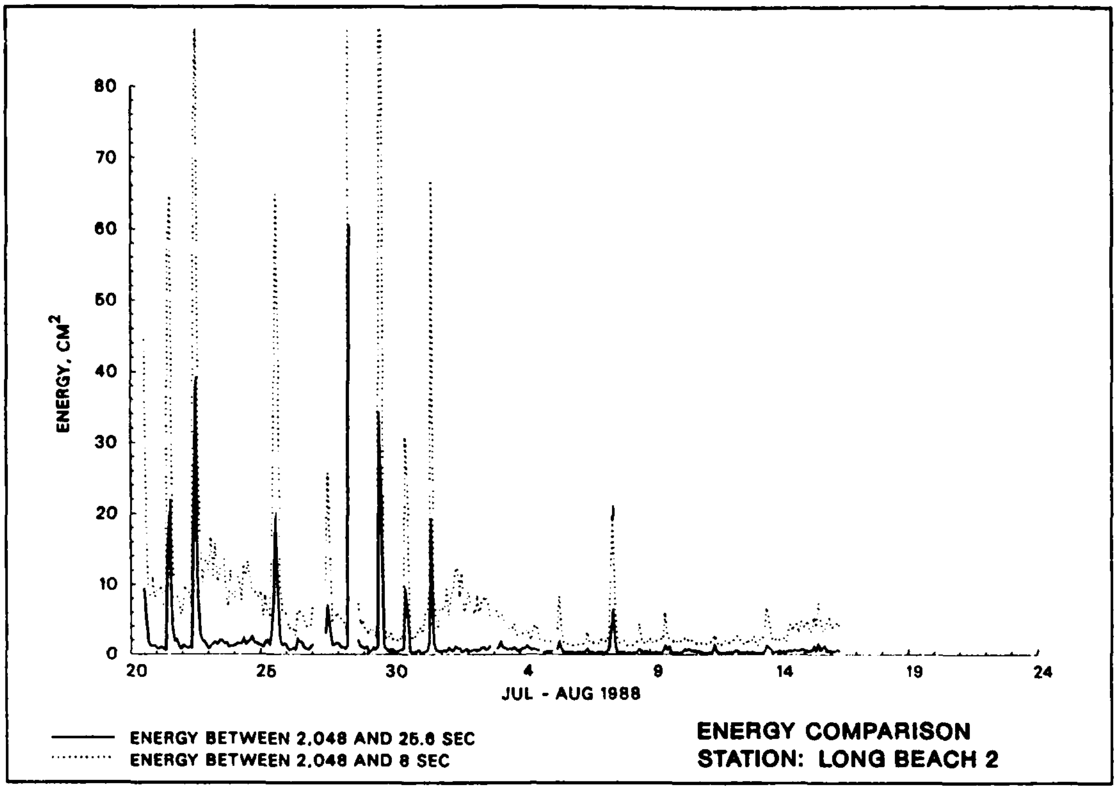

Figure 19. Energy spectrum from Long Beach Harbor, Station 2, showing anomalous energy values

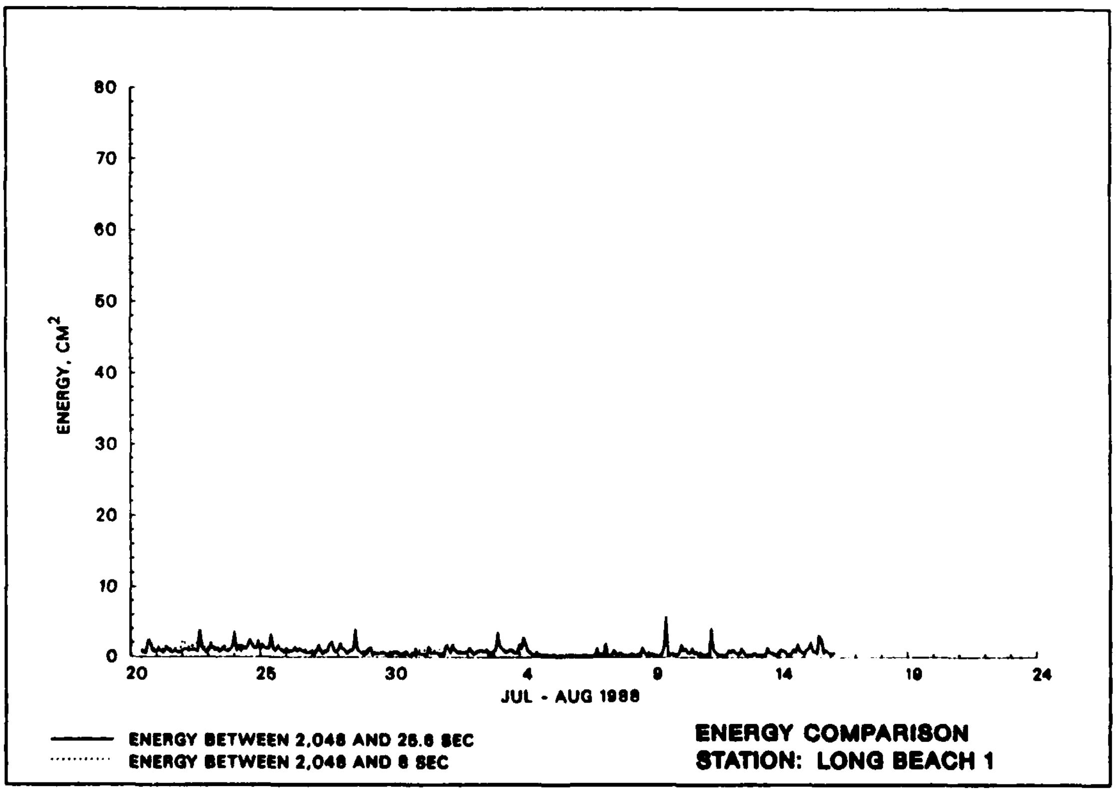

Figure 20. Energy spectrum from Long Beach Harbor, Station 1. The generally low energy contrasts with the energy peaks recorded at the Station 2, only a few hundred meters away

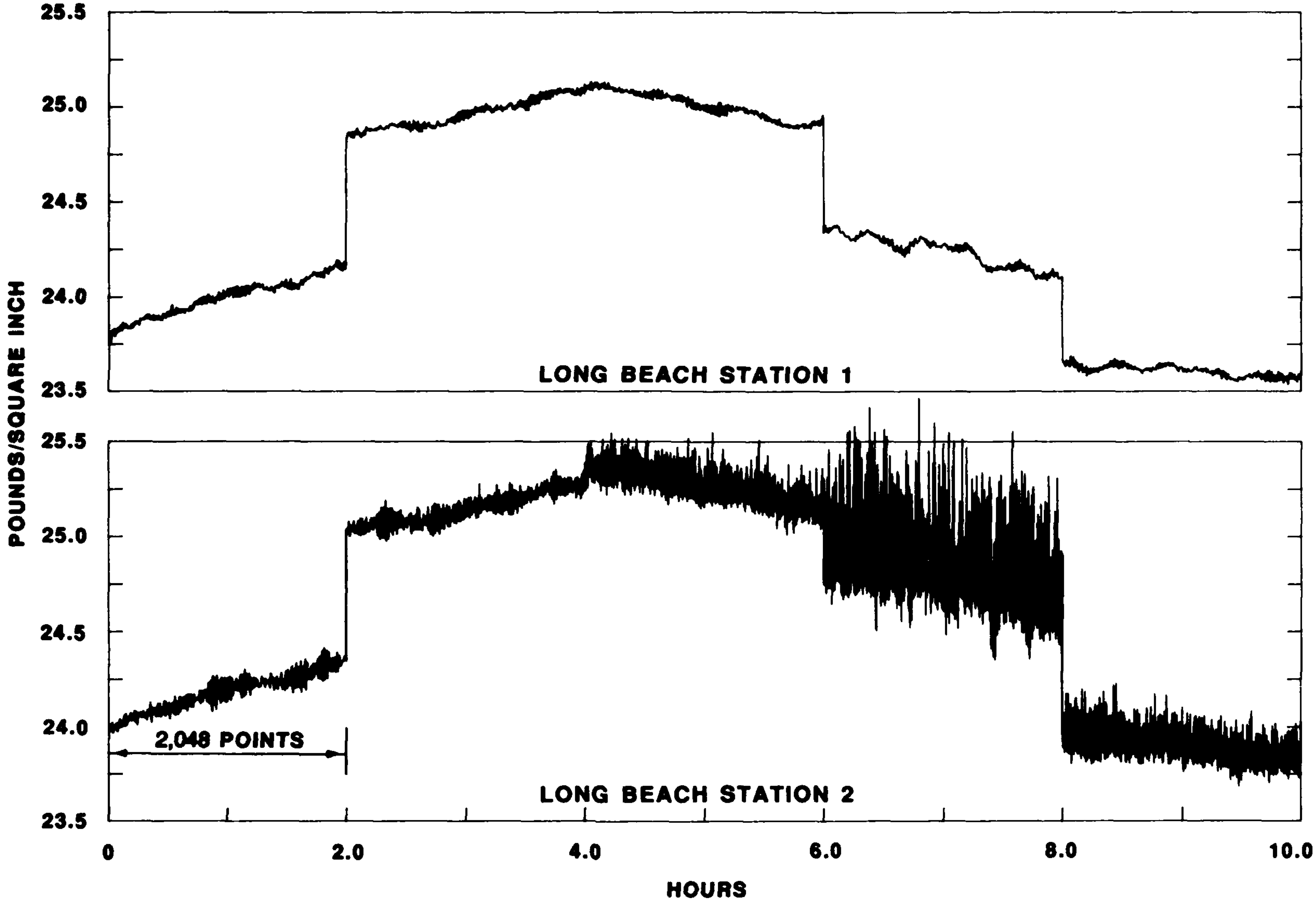

Figure 21. Comparison of pressure data from Long Beach Station 1 (top) and Station 2 (bottom), where significant changes in energy occur within a few hours. The vertical offsets represent tide changes that occurred while the gage was inactive between recorded wave bursts (see paragraph 9)

the measured mean current. But, in the 635-9 gage, the mean current is not measured, and, since there is no independent check of the overall velocity, a processing error is likely to occur if a bad point is abnormally high. If the computer program checks only one point when it calculates the rollover, the following values may be too high by a factor of one or even two cycles of 256. In Figure 22, the upper plot shows an example of a rollover jump. To correct the problem, the software was modified to keep a running record of the average positive and negative orbital velocities and to compare each new point with these averages. In the lower plot, the erroneous point that caused the original error can be seen.

Time shifts

50. Time shifts caused by segments of bad data. The processing software must keep a count of the length of each wave burst, and must know where each one begins and ends. If there are missing or bad lines of data, the program must flag them with the right number of points so that the affected burst will be the correct length. If the bad sections occur at the end of one burst or the beginning of the next, there is an increased chance that the software will be unable to calculate locations of the missing points. Figure 23 illustrates a subtle example of time shift. The tabular printout showed that the recovery occurred exactly 1 day later than the field technician recorded in the log. The technician's notes were accurate. There were many sections of bad data in this data set, and the software erroneously shifted the data by a total of eight bursts. Since the gage had been set to sample wave bursts every 3 hr, the total time shift equaled exactly 1 day. The lower plot in Figure 23 shows the original, shifted data. Bursts 405 and 406 are erroneous. The upper plot shows the data after it had been retransferred, resulting in a much cleaner data set. By comparing the bursts, number 416 on the lower plot, for example, is the same as number 408 on the upper, except that it has been moved to the right by eight places.

Conclusions

51. This report has reviewed quality control and troubleshooting of ocean wave data. Emphasis was placed on the human element as a vital part of the quality control of a wave measurement project. Three broad classes of

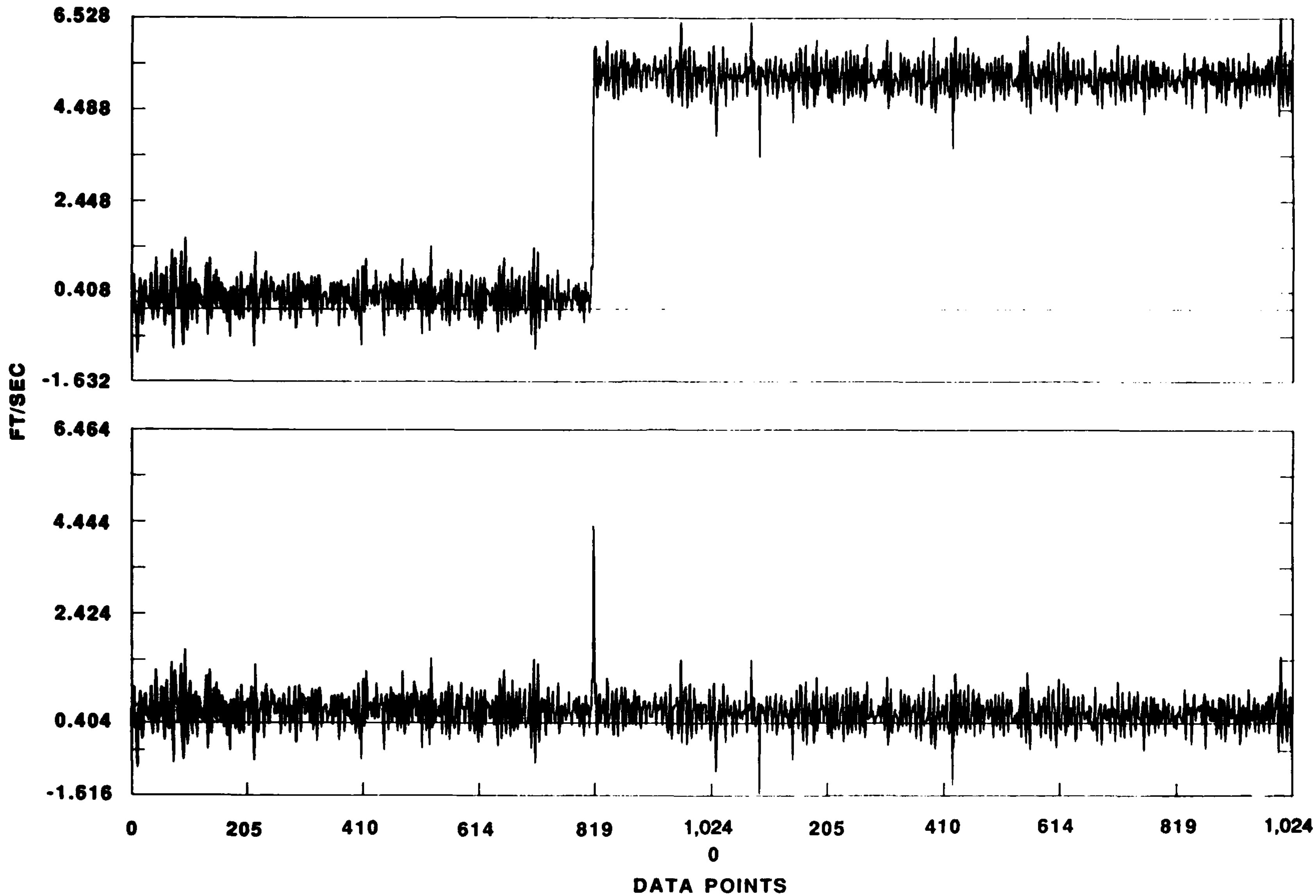

Figure 22. Upper plot shows an incorrect jump in velocity values, caused by a software error. The lower plot is the same data, reprocessed with corrected software

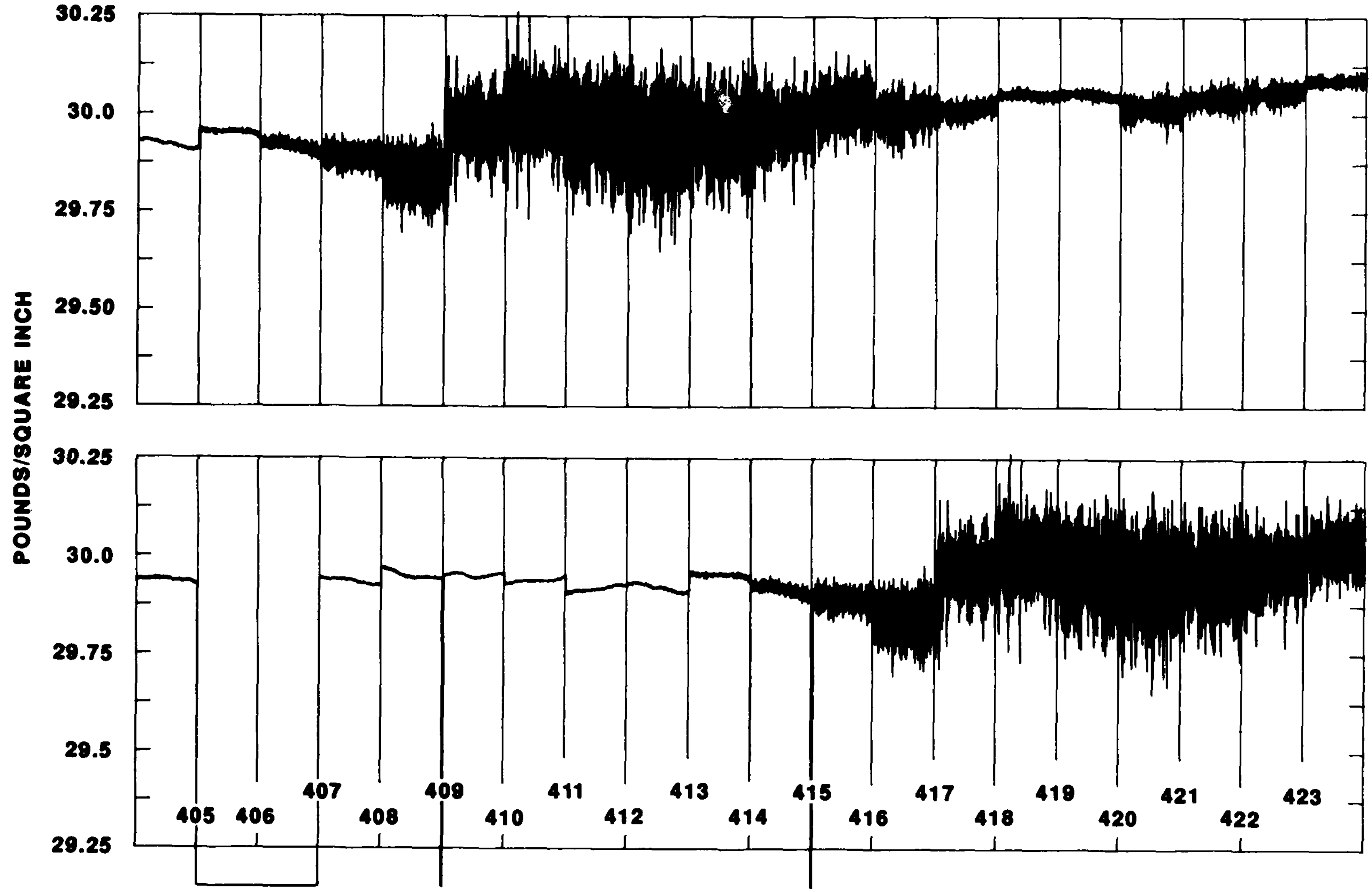

Figure 23. Example of data shift, the result of software incorrectly adding points to complete partial wave bursts. The lower curve shows how the data have shifted to the right a total of eight bursts

errors have been reviewed: gage malfunctions, data-transfer errors, and software problems.

52. The examples presented in this report illustrate two important aspects of quality control: first, there is no substitute for careful, visual examination of the data; and second, the evaluation of the data has to be made in light of where it was collected. The analyst must be aware of what wave heights and periods typically occur at the site and whether any unusual storms were reported during the project. No general rules can be applied universally, because wave conditions are so different around the world. In some areas, the energy can increase so dramatically within only a few hours that spectra appear to have erroneous spikes. The analyst must not discredit these results unless he is absolutely certain that an error has occurred somewhere in the analysis or data collection. Of the three broad classes of errors, malfunctions of the gage during deployment are the most serious because only rarely can the data be reconstructed, and then only if there is another gage nearby against which a comparison can be made. It is vital that the gages be meticulously maintained and tested. If the waves at a particularly critical location must be measured, two or even three gages should be deployed simultaneously. This practice is expensive, but the redundancy greatly improves the chances that usable data will be recorded.

53. Data-transfer problems can cause unexpected results. Fortunately, the problems often can be corrected by retransferring the data after cleaning or adjusting the tape readers.

54. Software problems are especially frustrating to the analyst, but these, too, can often be solved when the specific conditions of the project site are considered. For example, automated spike-check routines can be fooled where abrupt changes in wave energy occur, so the analyst may have to adjust the thresholds in the programs.

55. A wave-measurement project must be organized and planned from the outset with quality control as a vital component. The gages that will be used at the site must be tested long before deployment so that any needed repairs can be made and the gages tested again. Any unusual combination of gage settings (burst length, mean sample interval, etc.) must be tested to ensure that the gage actually does perform as specified. And, if at all possible, the deployment should be planned so that the gage will be recovered before the

tape is fully used so that the recovery times can be compared with the recorded clock times.

56. Complete and accurate field notes are also vital. In particular, the times of deployment and recovery must be recorded and, ultimately, must match the times on the data tape. A mismatch may indicate a problem during the tape transfer or a gage malfunction.

57. The state of knowledge regarding the measurement and analysis of waves is developing rapidly. Newer instruments are designed with more redundancy in the data collection, storage, and transfer procedures, so that many errors are automatically corrected. Gages without tape drives eliminate one set of errors but may introduce others. In the future, advanced troubleshooting software, may be developed that is similar to the "expert systems" used in medical diagnoses, but, for the time being, there is no substitute for human intervention. Unfortunately, it is often difficult for researchers in different institutions to compare their results and methods. The author would welcome comments and suggestions from other workers in the field.